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Exploiting Witness Simulation for SCM

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***Abstract*— Supply chain management (SCM) is a considerable source of competitive advantage in a business world. Literature reveals the concept, technique and strategy applied in SCM is important in planning, scheduling and inventory management to limit the effects of fluctuation in demand. Integration of SCM concepts and business simulation is exploited to analyse the behaviour of real time business operations and explore strategies for improvements optimisation of the whole supply chain.**

Towards this end, supply chain modelling is presented using Witness simulation software with information gathered from a participating retail store on the demand/sales of bottled milk. This paper explores strategies to better manage and control the ordering system to limit the effects of fluctuations. Supply chain modelling and simulation is carried out to diagnose problems, evaluate possible strategies, improve operations and mitigate risk factors. An ordering strategy which is based on the daily basis system and previous week's sales is successfully developed and simulated. Simulation results of different ordering strategies are presented to show the effectiveness and potential of the proposed methodology. The results obtained demonstrate that an experimental strategy can be implemented in real time to limit the effects of fluctuation in demand.

***Keywords*— Supply chain management, Witness simulation, Discrete event simulation, Ordering strategy, Bottled milk**

I. INTRODUCTION

Every business company's ultimate criterion is to gain profitability. Facing increases in competition and customers who are smarter and demanding, many retail stores have started to re-evaluate the whole business supply chain to identify problems and places for improvement and in some cases to implement new strategies to optimize the whole supply chain [1].

Inventory control plays an important role in supply chain management (SCM) [2]. Properly controlled inventory can satisfy customer's demands, yet failing to react to the demand can lead to serious consequences [3]. Much research has been devoted to demand fluctuations resulting in the "bullwhip effect" [4]. The bullwhip effect observed in many supply chains causes excessive inventory [5]. One of the popular methods used to investigate the bullwhip effect is modelling and simulation [6,7]. Empirically, it has long been recognised that inventory fluctuations play an important role in the business cycle [8]. SCM is known to be important in limiting the effects of fluctuations in demand [9].

This paper aims to develop a direct method for the members of a supply chain to choose their stock replenishment strategy in a dynamic environment.

In most supply chains, the environment changes far faster than their organisations can respond. For example, a customer entering a store expects products to be available instantly. However, it takes time for products to be manufactured and delivered to the store. Unfortunately, fluctuation in demand occurs in daily life. Retail stores use different strategies to maintain the business activities at the highest efficiency. In this study, discrete event simulation was applied to analyse the inventory of milk sales in a retail store.

Occurrence of fluctuation in demand is one of the crucial problems in businesses [10]. Taking bottled milk as an example, orders are produced on a daily basis for the following day's demand and it is therefore vital for the store to be able to meet the demand in an uncertain demand situation. The occurrence of fluctuation in demand leads to stock out and overstock issues. Consequently, stock outs do cause buyers to turn to other suppliers which mean lost sales. On the other hand, overstock leads to increase costs for businesses as holding stocks are an added expense for the company in addition to issues of a product's shelf-life.

It is widely acknowledged that computer-based simulation is a powerful tool that enables decision-makers to improve operational efficiency via its ability to incorporate uncertainties that are inherent in complex real-time systems [11]. WITNESS is industry-standard simulation software that was selected for this study as it has the ability to model a wide range of process and operation tasks [12]. By utilising Witness, a supply chain model can be built and tested eliminating the need to physically carry out tests in the retail store. The model can then be modified and adapted in a number of ways in order to reach a favourable outcome. For this study, the goal was to reduce the effects of fluctuation in demand.

A. *Limitations of Study*

The study was related to the background and operation of a retail store. The store manager was generally suspicious of the motives of any investigation because of fear of competition and taxation. For these reasons, there were a few disadvantages in ascertaining the accuracy of information. Hence, fine care was taken to gather the data as accurate as possible. The data gathered was dependent on many factors such as seasonal variation which has not been considered.

The objective of the study was to examine the events of the whole milk supply chain. Few local stores were considered but Store X was chosen due to its location, size, popularity and willingness to cooperate in this study. Whilst other retail stores in the vicinity were considered, Store X appeared to be the most appropriate. Store X is part of an international food retail chain that was established in 1953.

B. *Operational Details*

Information about how Store X operates was obtained by interviewing the manager. It was realised that there were basically two types of ordering system categorised by two types of product: daily products and longer shelf life products.

The ordering and delivery of the daily products such as milk, sandwich, fruits, vegetable, etc. run for 6 days a week. An order and delivery for longer shelf life products such as frozen goods, cigarettes, magazines, etc. is made once a week for replenishment. Store X headquarters (HQ) controls the amount of stock needed to be delivered with assistance from the store manager. Both the ordering systems are based on the level of inventory and sales of the particular product. In addition, the term dates of university are also taken into account which leads to cutting down the number of orders by 25 percent for a specific item.

Forecasting demand for daily products is done using previous week's sales data. Due to a short delivery period, orders are made in the morning and the goods arrive in the next morning. On the other hand, the HQ forecasts demand for the longer shelf life products based on the previous year's sales and orders. The sales and demand patterns of the previous year are made available by HQ for the store manager to view during ordering. Due to physical location of the store (i.e. it is located in a University area surrounded by offices), there is a substantial variation in sales volume throughout a year. For instance, during Christmas time the sales volume drops and the manager has to lower the percentage of orders through the HQ. For this study, the focus of discussions was Store X's own branded bottled milk.

C. *Specific Problem and Issues*

There are many local retailers that face fluctuations in demand. They might not be necessarily encountering the same problems as faced by Store X. However, every retailer's aim is to make and increase profit. Re-designing the whole supply chain may help the company to achieve its aim. There is a lack of visibility from the placement of purchase order to receipt of the goods by Store X. This is probably due to not well understood relationship between the suppliers and the retailer.

One of the major problems that Store X is facing is the high inventory levels and low inventory turnaround ratios due to its inability to forecast customer demand. Retailers obtain goods from the suppliers and sell them to the consumers while minimising inventory levels, warehousing and transportation costs. Retailers must maintain the balance between having sufficient inventories to avoid stock outs and keeping inventories level low at the same time to minimise holding costs and respond to ever-changing customer demand.

II. Business Strategy

The aim of the business strategy is to utilize the company's core competencies to set up and sustain a unique strength or focus that leads to a sustainable competitive advantage. For example, by keeping the price for a milk product lower compared with other competitors. If the quality of the product is acceptable, then the company can adopt a competitive pricing policy that will gain profitable volume. On the other hand, a company can have outstanding strength such as shorter lead time, advanced technology, better quality, brand name, etc. that differentiates the company from the competitors and is valued in the marketplace. A differentiation strategy defends against competitors because brand loyalty to differentiated product offsets price competition.

Store X has its own-brand of products with premium quality ingredients. This makes the store different from other competitors. Well differentiated products reduce customer sensitivity to price increase which leads to better profit margins, protection from competition, etc.

A. *Advance Planning and Scheduling*

In real time, there are many business issues which have a big impact on a company such as lost sales due to demand exceeding capacity which have a significant impact on revenue. Late deliveries due to manufacturing delays causes stock out situation and thus lead to loss in sales. Advance planning and scheduling technique resolves material, labour and capacity constrain simultaneously whilst minimising set up, maximising profit and meeting on- time delivery [13]. Advance planning and scheduling is the collaboration among sales, production, purchasing, planning, maintenance and management to effectively make a difference in the revenue [14]. It optimises a plan based on mathematical modelling techniques. Furthermore, it uses intelligent analytical tools to perform scheduling and hence produces a realistic plan to implement in real time business.

B. *Quality Management of Bottled Milk*

Milk has high nutritive value and its shelf life is short. The quality control of milk is designed to ensure it meets food hygiene requirements and to guarantee impeccable quality. Cost is associated with achieving and maintaining good quality of a product. It is important for a company to determine the appropriate level of quality of its products for the market it serves. Milk is a product which must be consumed within short period of time. Therefore, the time taken for milk from farm to the fridge has to be as short as possible to ensure high product quality.

Farmers milk cows twice a day. The milk is stored in a refrigerated tank until milk-tankers come to collect the milk on the next day. When a milk-tanker arrives, a sample of the milk is taken at every farm to make sure there are no antibodies in the milk. It is then taken to a dairy where further inspection is carried out to check for foreign bodies before it is pumped into the silos. The milk is then pasteurised to ensure there is no germs. It is then processed through the downstream activities of the supply chain [15].

C. *Forecasting Demand*

Precise demand forecasting is essential for any retail company to predict the amount of stock to keep as inventory to prevent the effects of fluctuations. On the other hand, the purpose of forecasting demand in production is to determine whether the demand is sufficient when evaluating a product. Auto-projection forecasting is used by Store X to determine the demand of bottled milk. It projects the past behaviour of the variable demand into the future by conducting a time series analysis which takes values of demand measured at regular time intervals.

D. *Inventory Management*

Inventory management is basically about identifying the curve pattern and percentage of stocked products in a period of time. There are many reasons for holding inventory. For instance, buffer inventories which are also called safety stocks are used to protect against the uncertainties of supply and demand or to mitigate against variations in lead time for a product [8]. Adequate safety stock levels permit business operations to proceed according to their plans. Safety stock serves as an insurance against stock out. The amount of safety stock a company chooses to hold dramatically affects the business. Excessive safety stock results in high holding cost of inventory and insufficient storage situation. In addition, products such as milk which when stored for too long may perish. Milk stored in a refrigerator for a day longer may make the product not fresh or best valued. On the other hand, too little safety stock results in lost sales and thus, a higher rate of customer turnover. In conclusion, a right balance of the amount of safety stock is crucial.

III. METHODOLOGY

This section explains the methods, techniques and tools implemented to the case study selected in this study. This includes selection of the software used, design of the simulation model and the theory applied.

A. *Witness Simulation Software*

Modelling and simulation of the supply chain management was done by using Lanner's Witness simulation software. Direct implementation of any technique or strategy in business world is not encouraged due to the uncertainty of demand and also many consequences. It would be very risky to implement any strategy without going through a detail analysis and evaluation. Business process simulation (BPS) provides an effective way for a company to evaluate impact of introducing a strategy on the supply chain. Witness simulation software was used in this study to create statistically accurate models to represent the behaviour of real life system and to subject them to predictive experimentation. The results from the experiments can then be used to answer the 'what if' type questions without risk or disturbance to the real life system.

B. *The Milk Supply Chain*

Modelling of the milk supply chain, figure 1, is started from the manufacturer or bottling plant to the other downstream activities. Manufacturer generates a large amount of milk daily to provide inventories to the distributors or suppliers. Milk products are then transferred to a depot where milk is kept and then distributed to the retail company according to the orders. Milk is distributed by a delivery van to each of the retail stores. Customers visit the retail store daily to purchase fresh milk.

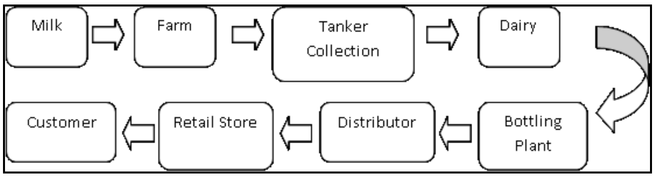

Fig. 1 The milk supply chain

C. *Techniques Adopted*

Demand is created at the end of the supply chain by customer purchasing milk from the store. A demand can be described as information or signal generated which travels upstream of the supply chain and milk is transferred downstream of the supply chain, figure 2. The flow in the chain is controlled by operation strategy and control planning.

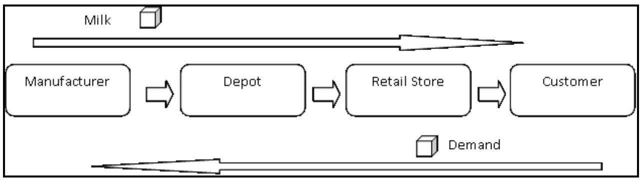

Fig. 2 Supply chain path

Strategies are developed in the simulation model based on different types of ordering system. The ordering system adopted in this study has mainly two elements:

- Order quantity
- Replenishment point

1) *Order Quantity:*

Occurrence of demand fluctuation is one of the major issues in business operation. Demand of consumers is uncertain and thus influences the replenishment order quantity (also known as re-order quantity). Auto projection forecasting technique is adopted to deal with the uncertainty. For auto projection forecasting, measurement of the amount of inventory at a specific point in time and the unit sold over a period of time is taken into account to predict future demand behaviour. The amount of inventory replenishment is calculated based on three major methods: previous day's sales; moving average technique; and previous week's sales.

2) *Replenishment Point:*

Inventory management is important to determine the point where new orders are made. Stock checking is carried out to evaluate the current state of inventory and determine whether replenishment is needed. To this end a crucial factor is to determine when new orders (or re-orders) should be made. The re-order point is determined by considering three theories: re-order point theory (ROP), periodic review system, and the daily review system.

IV. MODELLING THE SUPPLY CHAIN

Once the processes and procedures had been understood, modelling of milk supply chain began. A set of sales and ordering data was obtained from Store X through interviews and it was implemented in the simulation model. Modelling the supply chain was divided into following phases: Data Collection and Input, and Model building.

A. Data Collection and Input

The supply chain of bottled milk was explained earlier in figure 1. The data associated with the 'Input,' 'Activities' and 'Output' parameters of the milk supply chain is shown in table 1.

TABLE I
INPUT – OUTPUT PARAMETERS OF THE MILK SUPPLY CHAIN

Input	Activities	Output
Milk	Manufacturer	Sales
Orders	Depot for storage	Demand
	Picking process	
	Delivery	
	Retail store	

Milk is collected from the farm and transferred to the manufacturer at 7 a.m. for undergoing pasteurisation process. At 11a.m, the processed milk is stored in large refrigerators in the depot. Orders are generated at the same instance and a picking process is carried out according to the orders generated. Milk is picked up at 4a.m the next morning and transferred to the delivery van for delivery. Milk reaches the retail store at 6 a.m. with the exact amount that was ordered. Customer demand is generated daily according to the sales information obtained from Store X. A typical weekly sales record is shown in figure 3 for the 1 litre bottle sized semi-skimmed milk.

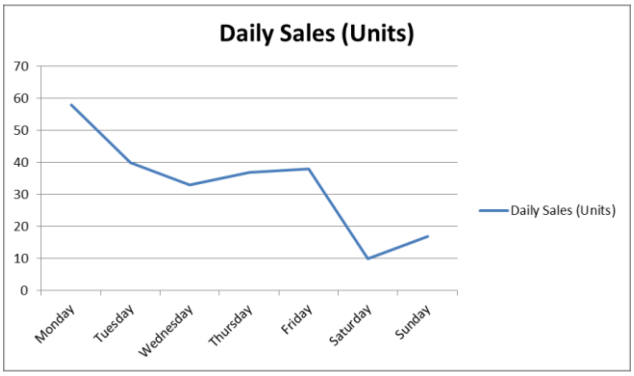

Fig. 3 A typical sales record of bottled milk (1 litre semi-skimmed)

B. Model Building

The different stages and/or operations of the milk supply chain were modelled using Witness software as shown in figure 4. The purpose of the model was to evaluate the impact of introducing different strategies into the business operations in real time. The different stages and/or operations included in the model were manufacturing, depot, picking process, order generation, retail store and customer demand. The simulation model is a tool to carry out experimental analysis and then evaluation of potential improvements. The randomness and variability experienced in real time is also taken into account within the simulation. The modelling aspect is categorised into the following steps: Elements, Input/Output Rules, Logic and Control Rules, Distributions, Resource Management, and User display. To analyse and interpret the behaviour of the constructed model, a visual display was devised and labelled as the management information systems (MIS). The MIS comprises of a screen display depicting a table of results which is updated dynamically during the simulation. The MIS displays the current sales, previous week sales, inventory levels, order quantity, stock levels carried forward, etc.

After some validation and verification the base model of the milk supply chain was finalised as shown in figure 4. Different types of stock ordering strategies based on (1) ROP theory, (2) Daily Review System, (3) Periodic Review System were devised for experimentation purposes. The purpose of utilising these different strategies was to explore the effects of demand fluctuations.

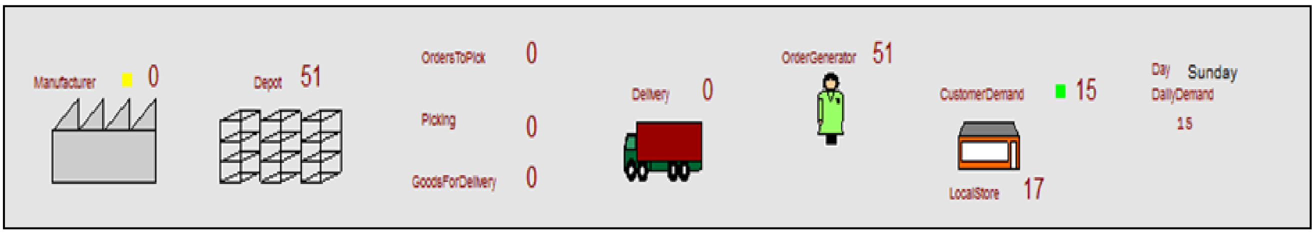

Fig. 4 Milk Supply Model in Witness

V. EXPERIMENTATION AND RESULTS

The overall objective of the study was to evaluate the performance of the milk supply chain. Strategies relating to the ordering of inventory replenishment were devised. Safety stocks of 10 units were included in the simulation. To calculate the profit gained, inventory cost and sales cost were included in the simulation where each unit had a cost of £0.80 (Pounds) and a retail sale price of £1.00 (Pounds). Witness models representing scenarios for each of the five different stock ordering strategies (described below) were simulated for 30 days.

A. Strategy 1: ROP and fixed maximum level of inventory

When the ROP is reached, a purchase requisition is made out. The reorder quantity of this strategy is based on the fixed maximum desired level of inventory. The simulation result is displayed in figure 5.

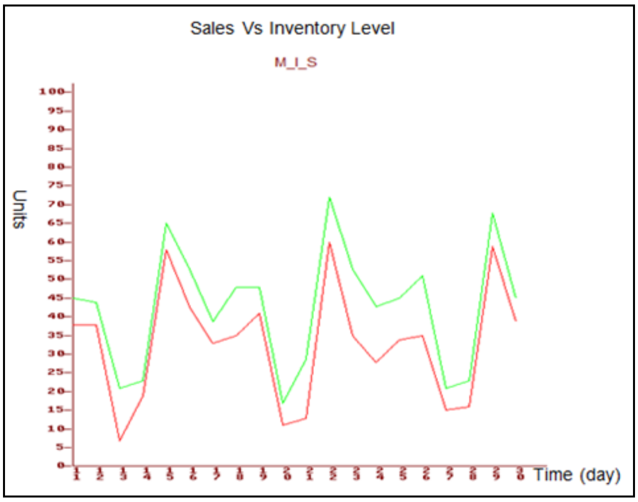

Fig. 5 Strategy 1 – Sales (red) vs. Inventory (green)

From strategy 1, the total profit gained in 30 days is £201. Figure 5 indicates 3 occasions when a shortfall has occurred. Stock checking is carried out when the ROP is reached (a certain level of inventory between max. and min. inventory level). Therefore, the ordering is not made on daily basis. The ordering is made averaging 4 times per week. The shortfall occurred mostly on Tuesday because most sales happened on Monday and at that instance review of inventory is not made. Therefore, there is no inventory replenishment on Tuesday which leads to stock out situation. There is an inconstant holding inventory level that caused the holding cost to increase.

B. Strategy 2: ROP and previous week's sales

The quantity of inventory to order is based on the previous week's sales. The simulation result is displayed in figure 6.

Using strategy 2, figure 6, a total profit of £227 is achieved in 30 days with no shortfall occurred. The ROP is met daily due to the good accuracy of forecasting by using the previous week's sales as prediction for today's demand. The gap between sales and the inventory level is small where the bigger gap is due to the safety stock issue and a little effect of fluctuation in demand. Moreover, a low level of holding inventory (average 10 units) is recorded by implementing this strategy.

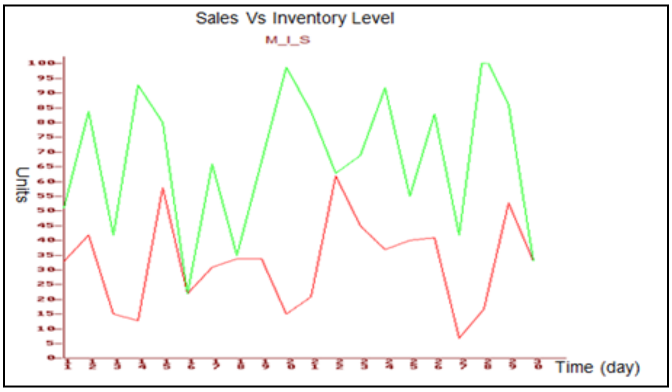

Fig. 6 Strategy 2 – Sales (red) vs. Inventory (green)

C. Strategy 3: Daily review and previous week's sales

Inventory review is carried out daily and an amount of inventory is being ordered at that instance. The quantity of inventory to order is based on the previous week's sales. The simulation result is displayed in figure 7 for sales vs inventory and holding inventory levels shown in figure 8.

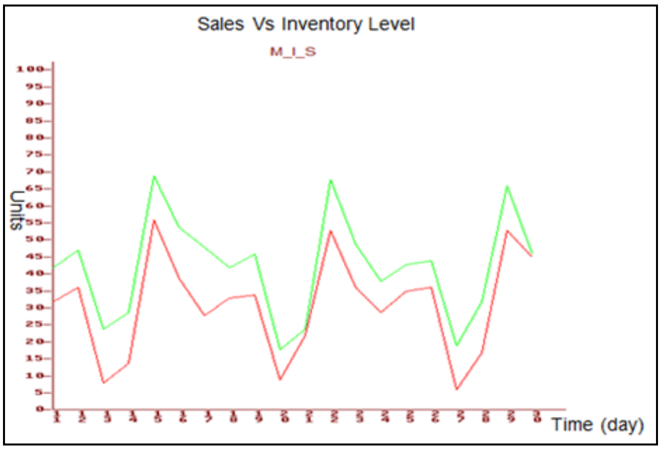

Fig. 7 Strategy 3 – Sales (red) vs. Inventory (green)

Using strategy 3, shown in figure 7, a total profit of £226 is achieved in 30 days with no shortfall occurred. The ordering and inventory checking is carried out on daily basis system. The amount to order for replenishment is based on the previous week's sales. Strategy 3 is similar with strategy 2. The only difference between the two strategies is the ordering system of strategy 2 is based on the ROP. A low level of holding inventory (average 10 units) is recorded by implementing this strategy as shown in figure 8.

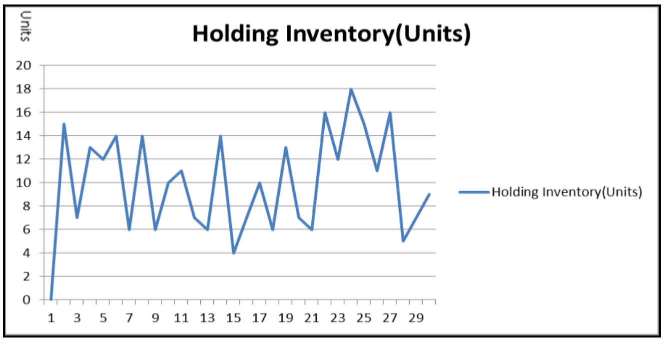

Fig. 8 Holding inventory levels for strategy 3

D. Strategy 4: Daily review and moving average

Daily review system is implemented together with the moving average technique where the ordering amount is based on cumulative average of last two weeks sales. The simulation result is displayed in figure 9.

Fig. 9 Strategy 4 – Sales (red) vs. Inventory (green)

Using strategy 4, figure 9, a total profit of £145 is achieved in 30 days with 3 occasions when a shortfall occurred. All the shortfalls occurred in the early few days of simulation probably due to the warm up period and thus the shortfalls can be neglected. The strategy produced a high amount of inventory level in the end of a week due to the demand fluctuation where demand is becoming lesser towards the weekend. The inventory brought into the store on Sunday is sufficient to be sold on Monday which has the peak demand of a week. On the gloomy side, there is a huge amount of wastage where holding stock for more than two days is not suitable for sale. Therefore, the profit gained is lesser.

E. Strategy 5: Periodic review and fixed maximum level of inventory

The reorder quantity of this strategy is based on fixed maximum desired level or inventory. The inventory level is checked once every two day, and at each review a reorder is placed for replenishment of inventory. The amount of the reorder is based on a fixed maximum level set up for each inventory. Demand over lead time is replaced by the average sales in a week because fluctuation occurred and thus the average of sales is taken into account. The simulation result is displayed in figure 10 for sales vs inventory.

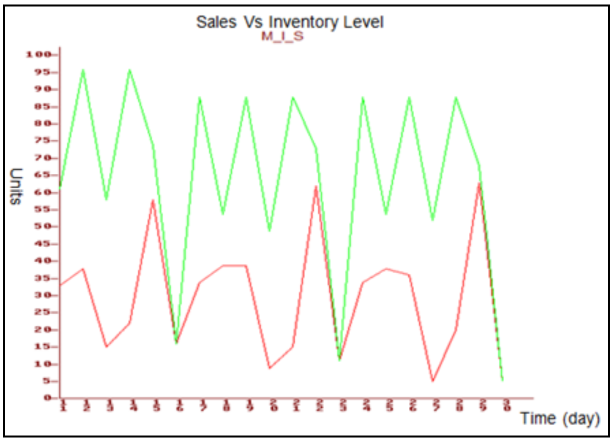

Fig. 10 Strategy 5 – Sales (red) vs. Inventory (green)

For strategy 5, figure 10, a total profit of £205 is achieved in 30 days with 4 occasions when a shortfall has occurred. Shortfalls have occurred in the beginning of a week. Most shortfalls have occurred on a Tuesday due to the amount of orders on a Monday. In addition to the holding inventory, it is not enough to meet the demand on Tuesday. The high demand on Monday has led to this situation. Therefore, the fixed maximum level of inventory ordering system is not effective to deal with fluctuation in demand problem. Moreover, there is quite high level of holding inventory on the other days.

F. Summary

Strategy 2 and 3 has resulted in maximum profits over the course of 30 days. Strategy 3 is more preferred on the basis of quality of milk. It is recognised to have ordering and delivery system that operates daily because milk is perishable goods where the longer the milk stays in store, the lower the value of the product. By implementing strategy 3, the gap between the demand and inventory level is narrowed down where inventory in store is sufficient to meet the demand.

VI. Discussion and Conclusions

The study of a milk supply chain has been conducted in collaboration with retail Store X. It has been realised that advance planning, scheduling and inventory management techniques play an important role in the supply chain management which theoretically limit the effects of fluctuation in demand.

Natural seasonal variation was not considered in this study. It was realised that there were some limitations of applying ROP theory:

- Products demand is uncertain
- Late delivery of ordered inventory which is crucial in Just in Time (JIT) system
- The reorder point which is the average demand does not represent lead time demand

Simulation of the milk supply chain by using periodic review system has shown that it is not suitable to be implemented on milk supply chain in real time. The disadvantage of the implemented system is that inventory level is not being checked until the review system is actioned. On the bright side, since the inventory level is checked periodically, the executive cost of the system can be less than a fixed (economic) order quantity (EOQ) model. Strategy 3 which is a daily basis systems where the amount ordered reflects the previous week's sales has shown to be far more advantageous than the other strategies. Strategy 3 has resulted in greater profitability. Secondly, as shown in figure 7, the gap between demand and inventory is minimised without stock outs.

In conclusion, strategy 3 has achieved a good balance in meeting the demand fluctuations and controlling the quality of milk available to the customers. Since milk is a perishable product the goal of the supply chain is to deliver it to the end-user in a fresh state. Supply chain management has been recognised as a means of providing rapid flow through. As a result of this study Store X has taken on-board these findings and has started to re-evaluate the supply chain and its methods of ordering milk on a daily basis. Clearly advance planning and scheduling and inventory management is the key to resolve the demand fluctuation issue. The strategy developed in the milk supply chain model using Witness simulation was well accomplished and demonstrated to limit the effects of fluctuation in demand.

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